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Canada Centre for Mineral and Energy Technology
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UTILIZATION OF STIFF BACKFILL IN ALLEVIATION OF ROCKBURSTS PART 1: PRE-MINING GROUND STRESS DETERMINATIONS AT THE MACASSA MINE

B. ARJANG

MRL 91-089 (TR)

JULY 1991

Canada

92-01188/

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MICROMEDIA

20 pp

UTILIZATION OF STIFF BACKFILL IN ALLEVIATION OF ROCKBURSTS
PART 1: PRE-MINING GROUND STRESS DETERMINATIONS AT THE MACASSA MINE

B. Arjang*

ABSTRACT

In the context of the Canadian Rockburst Research Program, utilization of stiff backfill has been investigated at the Macassa Mine of Lac Minerals Ltd., Kirkland Lake, Ontario. The objective is to demonstrate the effect of cemented rockfill as a local and regional support measure for rockburst control in narrow steeply-dipping orebodies. The extensive research project includes field and laboratory investigations and numerical modelling. As part of the underground field investigation to assess the stress regime around the selected test area, pre-mining stresses were determined at depths of 1440 m and 2005 m below surface. The stress data will provide the essential input parameters for the proposed model studies.

An evaluation of present, and the previously conducted, ground stress determinations by overcoring strain relief measurements indicates that the maximum horizontal stress prevails in a NNW direction and the minimum horizontal stress is oriented in a SWW direction. In relation to the main trend of the steeply-dipping orebodies and/or ore-bearing structures, the maximum horizontal stress is oriented perpendicular and the minimum horizontal stress is aligned on strike. The ratio of the maximum to minimum horizontal stress varies from 1.3 to 1.6, and the ratios of maximum and minimum horizontal stresses to vertical stress range from 1.3 to 1.8, and 1.0 to 1.3, respectively. From the average stress gradients, the pre-mining vertical stress and horizontal stresses perpendicular and along the ore-bearing structures are:

Vertical stress	:	0.0260 MPa/m
Horizontal stress, perpendicular	:	1.62 x vertical stress
Horizontal stress, parallel	:	1.12 x vertical stress

Key words: Overcoring strain relief; Stiff backfill; Premining stress, Stress gradients.

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RECOURS AU REMBLAI COMPACT COMME MOYEN DE PRÉVENIR LES COUPS DE TOIT DANS LES MINES
PREMIÈRE PARTIE : MESURE DES TENSIONS SOUTERRAINES À LA MINE MACASSA PRÉALABLE À L'EXPLOITATION

B. Arjang*

RÉSUMÉ

Dans le cadre du Programme canadien de recherche sur les coups de toit, l'on a étudié le recours au remblai compact à la mine Macassa de la société Lac Minerals Ltd., non loin de Kirkland, en Ontario. Le but recherché était de démontrer l'effet d'un remblayage cimenté comme moyen de réduire le risque de coups de toit, à l'échelle locale et régionale, dans des gisements étroits très inclinés. Le programme de recherche sur place et en laboratoire, fort complet, comprenait le recours à des modèles numériques. Dans le cadre des travaux souterrains, les tensions pré-exploitation ont été mesurées à des profondeurs de 1 440 m et 2 005 m. Ces données constitueront l'intrant des études par modèles.

D'après l'évaluation des mesures actuelles et déjà prises du soulagement des tensions souterraines par surcarottage servant à confirmer les mesures de dégagement des tensions, les tensions verticales les plus fortes se situent dans un axe nord-ouest et les tensions horizontales les moins fortes dans un axes sud-ouest. Par rapport aux plans très inclinés des gisements et structures à minerais, les tensions horizontales maximales sont perpendiculaires et les minimales sont alignées dans le sens du gisement. La ratio entre les tensions horizontales les plus fortes et les plus faibles et entre les horizontales et les verticales oscille entre 1.3 et 1.8 et entre 1 et 1.3 respectivement. D'après les courbes de tension moyenne, les tensions pré-exploitation verticales et horizontales qui sont perpendiculaires aux structures à minerai et dans l'axe de ces structures sont les suivantes :

Tension verticales :	0,0260 MPa/m
Horizontales perpendiculaires :	1,62 x tensions verticales
Tensions horiz. parallèles :	1,12 x tensions verticales

Mots-clés

soulagement des tensions par surcarottage
remblai compact
tension pré-exploitation
courbe de tension

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INTRODUCTION

A proposal for the 'stiff backfill project' was submitted by Lac Minerals Ltd. to the Technical Advisory Committee of the Canadian Rockburst Research Program in October 1990. The approved research project with Lac Minerals as the main contractor, and CANMET and Golder Associates Ltd. as sub-contractors, consists of field and laboratory investigations and model studies. The objective is to demonstrate that stiff backfill reduces the severity, damage and number of rockbursts in narrow steeply-dipping orebodies. The initial research will be concentrated on the cemented rockfill (CRF) at Macassa Mine of Lac Minerals Ltd., Kirkland Lake, Ontario. This deep hardrock mine (2200 m) with narrow orebody provides the most suitable site for demonstrating the advantages of stiff backfill. However, it is intented to expand future research to other mining operations using similar backfill.

As part of the field studies for this project, pre-mining ground stress determinations were carried out at selected mine sites. The following summarizes the results.

Instrumentation in backfill, and in situ testings to determine the stiffness of backfill and laboratory work to investigate the application of a borehole dilatometer in CRF are in progress. The results of these investigations will be compiled in a follow-up report.

PROJECT ELEMENTS

In the context of the stiff backfill project at Macassa Mine, the proposed investigations were as follows (1):

1. Field Studies

   To select four to six 3.0 to 7.6 m wide test stopes with unconsolidated rockfill and CRF for instrumentation and in situ measurements in and around the test stope (to be conducted by CANMET, Elliot Lake Mining Research Laboratory and Lac Minerals Ltd.):

a) To measure pressure on backfill and convergence between hanging wall and footwall to obtain in situ stiffness of backfill and changes of stiffness with mining sequences.

b) To determine in situ ground stresses to establish the three dimensional stress regime in the area; biaxial ground stress measurements in the crown/sill pillars to determine stress levels in the different types of backfilled stopes; to install IRAD stress meters in the crown pillars to monitor the change in stress as mining advances.

c) To conduct extensometer and IRAD gauge measurements from hanging wall instrumentation drifts to monitor displacement opposite the crown pillar and backfilled stopes.

d) To drill boreholes into the CRF for dilatometer measurements as an independent means of obtaining backfill stiffness.

e) To use the microseismic and macroseismic systems of the mine to monitor the seismic activity around the test stopes.

The proposed pillar stress measurements using biaxial strain cells were postponed to a future date. With the almost complete conversion to undercut-and-fill mining, no crown/sill pillar situation was readily available to conduct these measurements.

2. Laboratory Studies

To be conducted by CANMET, Sudbury and Elliot Lake Laboratory (2e), to perform the following tests to identify:

a) Particle size analysis to determine the distribution and gradation of the aggregates.

b) Relative density of the aggregate to determine the packing characteristics of the fill materials.

c) Large-scale compression tests on CRF with varying binder percentages to determine the elastic modulus and compressive strength using both

normal Portland cement and flyash.

d) Confined tests on CRF with varying binder percentages to establish the increase in fill modulus with confinement.

e) To test the stiff borehole dilatometer in CRF using 45 gallon drums with an N-size centre hole.

3. Model Studies

To run an N-FOLD computer model (by Golder Associates Ltd.) on the instrumented stopes under the conditions of no backfill, rockfill and CRF, and to calibrate the model against the in situ measurement of fill pressure, stope convergence and the rock stresses. In addition, to carry out sensitivity analysis on varying stope widths, elastic moduli of the wall rocks, depth and backfill stiffness.

MINING BACKGROUND

The Macassa Mine of Lac Minerals Ltd. located in Kirkland Lake has been in production since 1933. The main mining methods employed at the mine were overhand cut-and-fill with recycled, unconsolidated waste development rock as backfill, and shrinkage stope in the upper mine levels. Since 1986, the ore has been extracted primarily by underhand cut-and-fill and underhand benching mining methods utilizing CRF. The main mining horizons, located 1200 to 2150 m below surface, are accessed from mine levels developed at about 46 m intervals. Previously the mine was serviced by two shafts and two internal winzes. The present access to the main mining development is a 2202 m deep single lift shaft. The majority of extraction is along the ore-bearing structures with a mining width ranging from 1.5 m to 15 m.

At the Macassa Mine over 500 rockbursts ranging from strain to pillar bursts have been reported in the past 58 years of operation. The majority of bursts occurred in the ore zone, i.e., stopes and pillars, which resulted in rock displacements of more than 1000 tonnes. The largest rockburst recorded

to date had a magnitude of 3.1 M_N. A review of rockburst incidents indicated high ground stresses, mining geometry, pillar configurations, the presence of brittle high-strength rock and the variation in rock stiffness as significant contributing factors to the occurrence of violent ground failures or rockbursts (2).

An improvement in the overall mine stability and an apparent reduction in the rockburst frequency has been achieved with the implementation of CRF in the mine (3). For the purpose of local and regional support, various mining methods are presently being tested using CRF. Portland Type 10 cement is mechanically mixed at a pulp density of 55% and is delivered either by gravity or pumping to the dump point. The slurry is then mixed with waste development rock. The cement binder ranges from 5 to 7% by weight of rockfill. To date, approximately 80% of active stoping areas are using CRF. Because of mining conditions, utilization of stiff backfill is expected to approach 100%.

GEOLOGICAL-STRUCTURAL SETTING

The geological-structural setting at the Macassa Mine reflects a complex history of intermittent folding, intrusive activity, ore deposition, faulting or fracturing, dyke intrusion and finally, post-ore faulting (4,5).

The main gold-bearing zones occur along, or in close proximity to, one of several fault systems which has been designated as the Main Break, or Kirkland Lake Fault. This fault system traverses the entire length of the mine as a 0.30 to 6.0 m wide weakness plane marked by a zone of mylonitized and brecciated wall rock, chlorite schist and gouge. The deeper mine levels exhibit a branching fault system forming a north and south branch to the Main Break. A significant sub-parallel fault is the '04 Break' connected to the north branch of the Main Break. The '04 Break' is the main ore-bearing structure in the west part of the mine. The fault systems have an easterly

trend and generally dip steeply to the south (N65°E/75°SSE).

Post-ore fault systems with a northerly trend occur as steep-dipping structures mainly at the west end of the mine. These structures have affected the major EW ore-bearing faults (Main Break and '04 Break').

The orebody is on average 2.5 m wide and is contained in various types of syenite, porphyry and tuff with pronounced joint sets, resulting in blocky masses of rock. Potentially unstable wedges and blocks defined by weakness planes are the main sources of structurally-controlled ground instabilities.

GROUND STRESS MEASUREMENTS

Ground stress measurements were carried out with overcoring strain relief technique using CSIR triaxial strain cells. Measurements were taken on the 4750 level and 6600 level at depths of 1440 m and 2005 m below surface. The stress measurement sites were located away from the influence of mining activity and the test holes were drilled from the mine openings with about 4.0 m^2 cross-section. The overcoring tests were commenced at distances greater than twice the diameter of mine openings.

An air driven type VAG drill machine (standard head with screw fit) capable of drilling a 99 mm diameter hole was used. The test holes were drilled at inclinations of 5° above horizontal. For overcoring, a core barrel bit was used which yielded an 83 mm diameter core. Prior to overcoring, the test hole was drilled with a diamond bit which yielded a 73 mm diameter core. The location and orientation of the stress measurement holes are shown in Figures 1 and 2.

The stress measurement hole on the 4750 level was drilled in a fractured, fine-grained tuff nearly perpendicular to the main structural trend. The test site was located in the hanging wall of the northeasterly striking '04 Break'. Some sub-vertical joints with slip planes at intervals of about 30 to 60 cm intersected the test hole. All overcoring tests carried

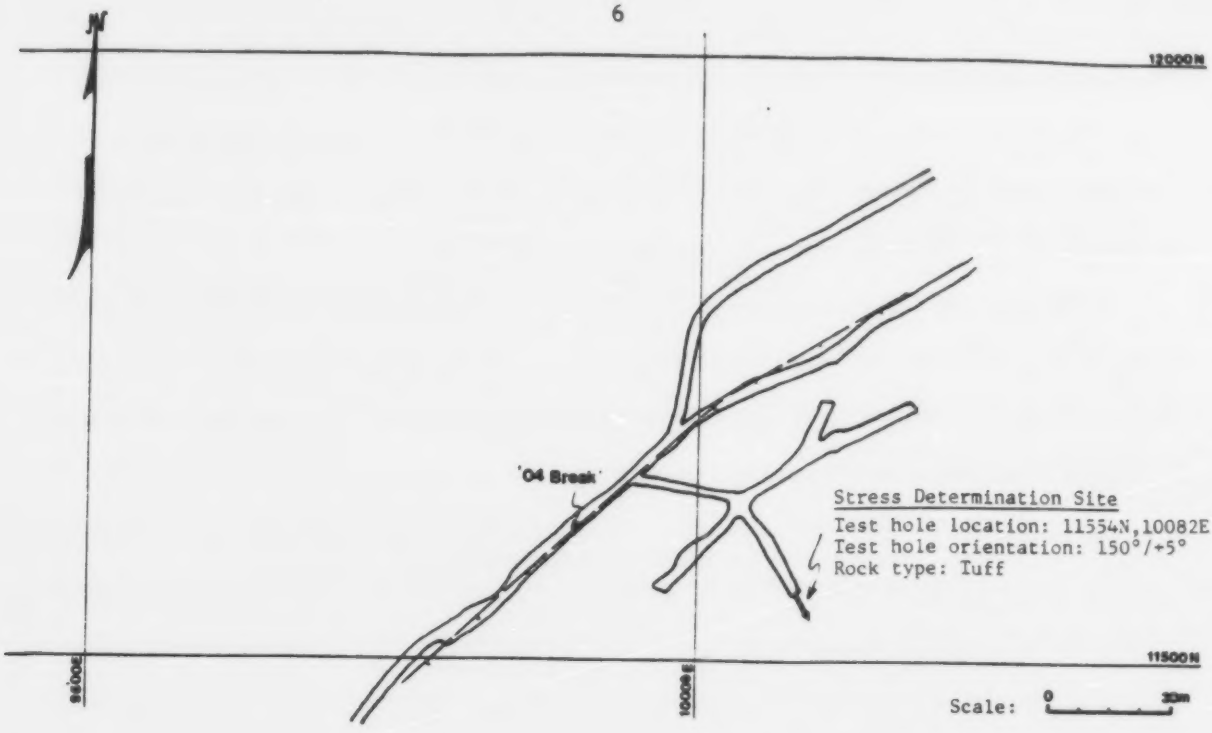

Fig. 1 - Stress determination site and test hole location on the 4750 level.

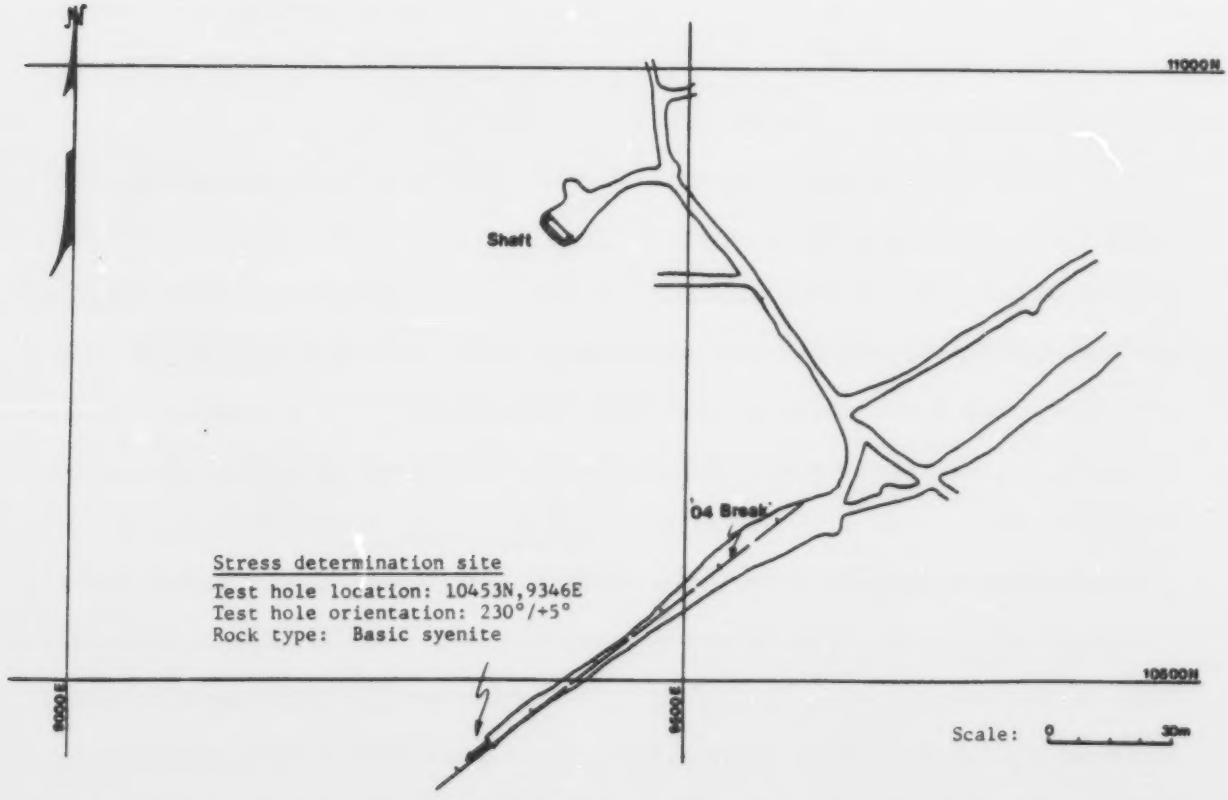

Fig. 2 - Stress determination site and test hole location on the 6600 level.

out at depths 3.63, 5.33 and 5.90 m from the borehole collar were successful.

On the 6600 level, the test hole was drilled in a highly fractured, fine-grained basic syenite. The test hole was aligned with the main structural trend at a distance of about 2.0 m from the hanging wall of '04 Break'. Joint sets with slip planes perpendicular to and along the axis of the test hole were intersected, resulting in continuous core breakage. However, two successful overcoring tests were done at depths of 4.55 and 5.00 m. The borehole was abandoned at a depth of 5.5 m because of highly fractured rock.

At the test sites the ambient underground temperature ranged from +20° to +25°C with 70 to 80% relative humidity. Successful bonding of strain cells in the EX-pilot holes was achieved using two component gauge adhesive cement, Versilok HI-406. The adhesive cement mixture (with a pot life of about 5 min) cured after 15 to 20 min. The overcoring commenced at a rate of 2.5 cm/min about one hour after the strain cells were installed. The strain recovery from overcoring measurements and the strain invariances for each strain cell rosette are given in Table 1.

STRESS DETERMINATION RESULTS

The results of stress tensor analyses from overcoring strain recovery measurements are given in Table 2. The stress components and the direction of principal compressive stresses are related to the mine coordinate system (Mine grid north = Geographic north). For completeness of data, the results of previous stress determinations (6), conducted on the 5300 and 6300 levels, are included in Table 2. These results are incorporated in the following to evaluate the stress regime at Macassa Mine.

The stress tensor analyses for the 4750 and 6600 levels are based on the following average elastic moduli (E), and Poisson's ratio (ν), which were determined from the overcoring test specimens containing the triaxial strain

Table 1 - Strain recovery data from overcoring measurements

Location (X)	Test No.	Depth (m)	Micro Strain Gauge No: 1	2	3	4	5	6	7	8	9	10	11	12	SI(*) A	B	C
4750 Level (1440 m)	MM 47-01	3.63	845	435	505	890	950	1000	495	430	685	915	620	480	25	15	90
	MM 47-02	5.33	685	905	640	470	1050	1200	585	510	995	540	455	900	50	75	10
	MM 47-03	5.90	805	670	740	860	1010	625	695	1090	990	1105	690	555	15	10	20
6600 Level (2005 m)	MM 66-01	4.55	1600	870	400	1150	1880	1580	100	370	1270	200	510	1550	20	30	30
	MM 66-02	5.00	1350	340	600	1660	2010	1790	510	650	1650	920	490	1205	50	80	15

(X) Depth below surface at the overcoring test site.

(*) Strain Invariance: sum of strain in two orthogonal directions, $\varepsilon_1 + \varepsilon_3 = \varepsilon_2 + \varepsilon_4$.

Table 2 - Stress components, magnitude and orientation of the principal stresses from overcoring measurements (stress in MPa).

Location (*)	Test No.	Stress Components (Standard errors in brackets)						Principal Stresses Magnitude/Brg. Dip		
		σ_{EW}	σ_{NS}	σ_{V}	τ_{EN}	τ_{NV}	τ_{VE}	σ_1	σ_2	σ_3
4750 Level	MM 47-01	33.6	44.6	35.3	-7.1	-8.1	7.0	55.1	34.1	29.3
(1440 m)		(2.3)	(3.7)	(2.3)	(1.8)	(1.8)	(1.3)	325/28	228/12	116/58
	MM 47-01	51.5	43.6	33.5	-10.3	1.7	1.4	58.5	37.6	32.2
		(3.0)	(5.0)	(3.0)	(2.4)	(2.4)	(1.7)	124/03	214/27	035/63
	MM 47-03	39.2	65.1	37.0	-5.7	-4.2	1.9	66.9	38.5	35.8
		(0.5)	(0.9)	(0.5)	(0.4)	(0.4)	(0.3)	348/08	254/25	095/63
5300 Level	MA 4-1	40.4	64.2	38.9	-6.6	5.0	-6.8	67.5	43.2	32.8
(1585 m)		(1.9)	(4.9)	(1.9)	(2.5)	(1.3)	(2.3)	343/13	062/40	088/47
	MA 4-2	53.1	46.3	31.8	-7.8	6.4	-8.9	62.2	41.2	27.7
		(0.1)	(0.4)	(0.1)	(0.2)	(0.2)	(0.1)	304/20	035/02	131/70
	MA 4-3	33.7	52.8	30.3	0.5	4.5	-3.0	54.1	33.6	29.2
		(3.7)	(6.0)	(3.7)	(2.1)	(3.0)	(3.0)	168/10	261/16	046/71
6300 Level	MA 2-1	61.1	80.7	50.9	0.4	9.1	-3.3	83.3	61.8	47.5
(1890 m)		(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.0)	359/16	265/13	138/70
	MA 2-2	39.3	66.1	35.2	13.1	13.9	1.7	75.9	36.1	28.5
		(1.7)	(3.7)	(1.2)	(2.3)	(1.4)	(0.8)	021/18	280/30	137/54
	MA 2-3	67.8	79.7	48.4	3.8	17.9	1.2	88.6	67.1	40.2
		(0.8)	(2.2)	(0.7)	(0.9)	(0.8)	(0.4)	012/24	280/05	178/66
6600 Level	MM 66-01	33.0	72.9	59.2	-0.9	-5.6	3.5	75.0	57.6	32.6
(2005 m)		(3.2)	(5.3)	(3.2)	(2.5)	(2.5)	(1.9)	357/17	198/68	090/07
	MM 66-02	53.3	75.6	60.7	-1.2	-13.7	-9.4	84.2	61.3	44.0
		(1.9)	(3.1)	(1.9)	(1.4)	(1.4)	(1.0)	008/32	123/33	246/40

(*) Depth below surface at the stress determination site.

Note: Stress components and the principal stresses orientation (Bearing/Dip in degrees) related to Mine grid north (= Geographic north). Elastic modulus (E) and Poisson's ratio (ν) used for stress tensor calculations: 4750 Level: E = 69.0 GPa, ν = 0.20; 6600 Level: E = 66.6 GPa, ν = 0.23. Stress data for 5300 and 6300 levels obtained from previous stress determinations (6).

cells:

4750 level : E = 69.0 GPa, ν = 0.20

6600 level : E = 66.5 GPa, ν = 0.23.

The orientation of the principal stresses on the 4750, 5300, 6300 and 6600 mine levels, and the general trend of main ore-bearing structures are illustrated in an equal area net, lower hemisphere projection, in Figure 3.

The stress determinations show that for individual test sites good agreement exists between the orientation of principal stresses. The maximum and intermediate principal stresses are near horizontal, and the minimum principal stress is sub-vertical with varying direction. The maximum and intermediate principal stresses on the 4750 and 5300 levels prevail NNW and NE directions, respectively. On the 6300 and 6600 levels, however, the maximum stress shows a NNE trend and the intermediate stress is in an easterly direction. This indicates an average clockwise rotation by about 37° with increasing depth, i.e., from 4750 level to 6600 level.

Figure 4 illustrates the combined direction of maximum and intermediate principal stresses (horizontal stresses) and the main trend of ore-bearing structures in an equal area net, lower hemisphere projection. The mean azimuth and dip of principal stresses are as follows:

Maximum principal stress, σ_1 : $346^\circ \pm 25^\circ/17^\circ \pm 8^\circ$

Intermediate principal stress, σ_2 : $250^\circ \pm 32^\circ/20^\circ \pm 12^\circ$

This suggests an overall orientation of NNW/horizontal for the maximum principal stress (maximum horizontal stress), and SWW/horizontal for the intermediate principal stress (minimum horizontal stress) at the mine site. In relation to the main trend of the steeply-dipping ore zones and the ore-bearing faults, generally, the maximum horizontal stress is oriented perpendicular, and the minimum horizontal stress is aligned on strike.

The variation of the sum of principal stresses as a function of depth, and the stress ratios and stress gradients from the stress determinations at

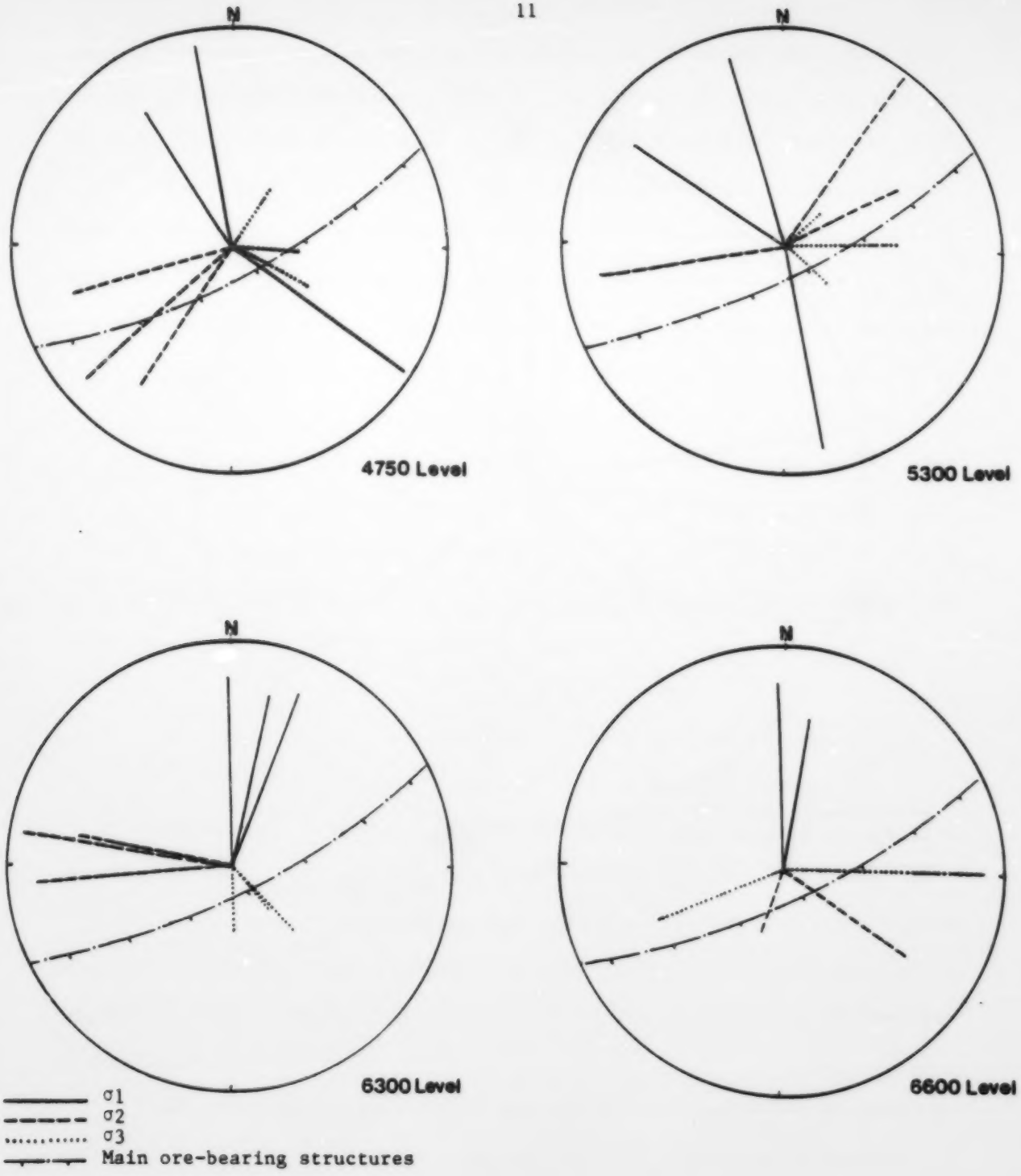

Fig. 3 - Orientation of the principal stresses from Mine grid north (=Geographic north).

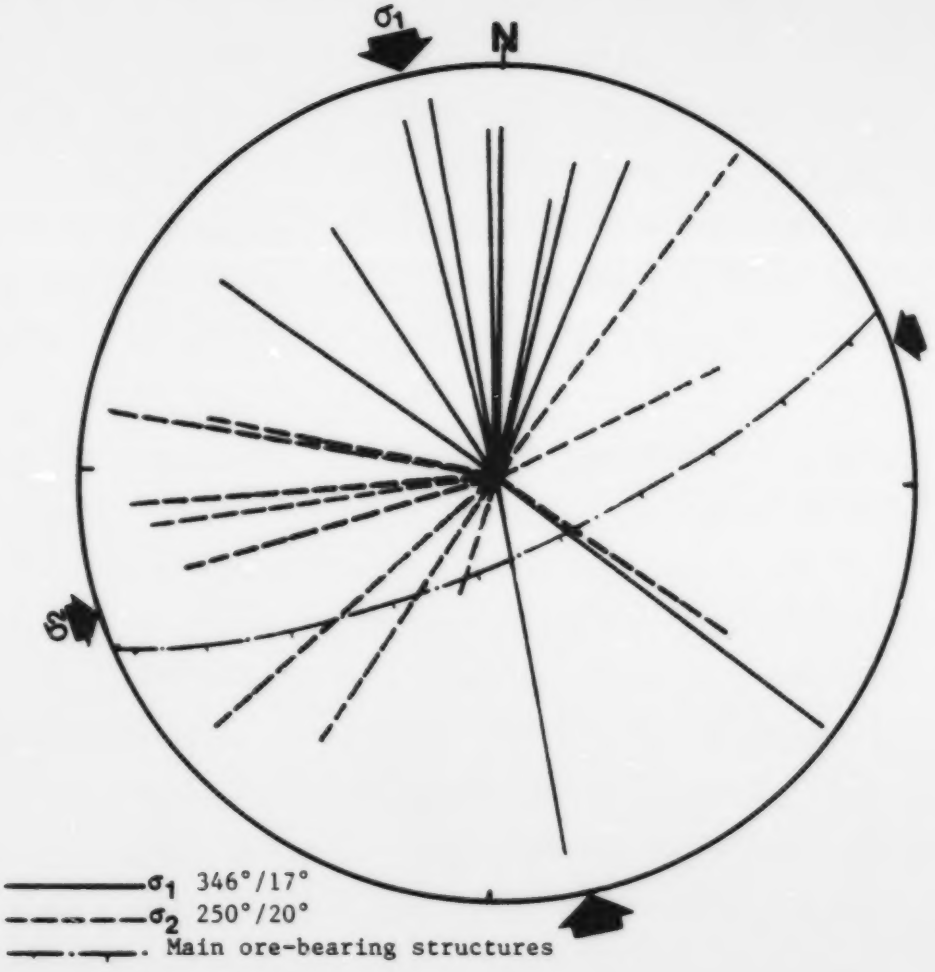

Fig. 4 - Orientation of maximum and intermediate principal stresses and the main trend of ore-bearing structures from Mine grid north (=Geographic north).

the mine are summarized in Table 3. An evaluation of stress data shows that the sum of principal stresses as well as the horizontal stress gradients on the 6300 level, are higher than values obtained from 4750, 5300 and 6600 levels. The results also indicate that the increase of ground stresses with depth is not linear. The ratios of the maximum to minimum horizontal stress vary from 1.3 to 1.6 with maximum and minimum horizontal stress to vertical stress ratio ranging from 1.3 to 1.8, and 1.0 to 1.3, respectively. The ratio of the average horizontal stress to vertical stress is in the order of 1.2 to 1.5.

The calculated stress ratios indicate a wide range of variation. For stability evaluations, however, from the average stress gradients, the following pre-mining vertical stress as well as the horizontal stresses perpendicular and parallel to the ore-bearing structures can best be approximated as:

$$\text{Vertical stress} = 0.0260 \text{ MPa/m}$$

$$\text{Horizontal stress, perpendicular} = 1.62 \times \text{Vertical stress}$$

$$\text{Horizontal stress, parallel} = 1.12 \times \text{Vertical stress.}$$

A comparison of stress values shows that the stress field at the test site on the 6600 level has possibly been affected by the ore-bearing fault ('04 Break'). This major structural plane, aligned with the stress determination hole, was located in close proximity to the test site. Apparently, some stress relief occurs close to the hanging wall of the ore-bearing fault.

Figure 5 shows the increase of the sum of principal stresses, maximum, intermediate principal stresses, and the vertical stress as a function of depth from the underground stress determinations in the Canadian Shield (7). The stress data obtained at the Macassa Mine are also plotted in Figure 5. A comparison suggests the present data follow the trend established in the Canadian Shield. Data plots, however, indicate that the stress gradients are

Table 3 - Sum of principal stresses, stress ratios and gradients

Location (X)	$\Sigma\sigma$	Stress Ratios				Stress Gradients (MPa/m)		
						Horiz. Stress		Vert. Stress
	(MPa/m)	σ_1/σ_2	σ_1/σ_V	σ_2/σ_V	K*	σ_1	σ_2	σ_V
4750 Level (1440 m)	0.0898 ±0.0080	1.63 ±0.10	1.70 ±1.10	1.04 ±0.07	1.37 ±0.09	0.0418 ±0.004	0.0255 ±0.001	0.0245 ±0.001
5300 Level (1585 m)	0.0866 ±0.0055	1.54 ±0.04	1.84 ±0.15	1.20 ±0.13	1.52 ±0.14	0.0410 ±0.002	0.0266 ±0.001	0.0223 ±0.003
6300 Level (1890 m)	0.0933 ±0.0164	1.33 ±0.02	1.73 ±0.14	1.30 ±0.12	1.51 ±0.13	0.0455 ±0.002	0.0341 ±0.002	0.0263 ±0.001
6600 Level (2005 m)	0.0884 ±0.0085	1.34 ±0.05	1.33 ±0.08	1.00 ±0.02	1.16 ±0.05	0.0397 ±0.003	0.0296 ±0.001	0.0299 ±0.001

(X) Depth below surface at the stress determination site.

(*) K Ave. $= \frac{\sigma_{Ha}}{\sigma_V} = \frac{(\sigma 1 + \sigma 2)/2}{\sigma_V}$

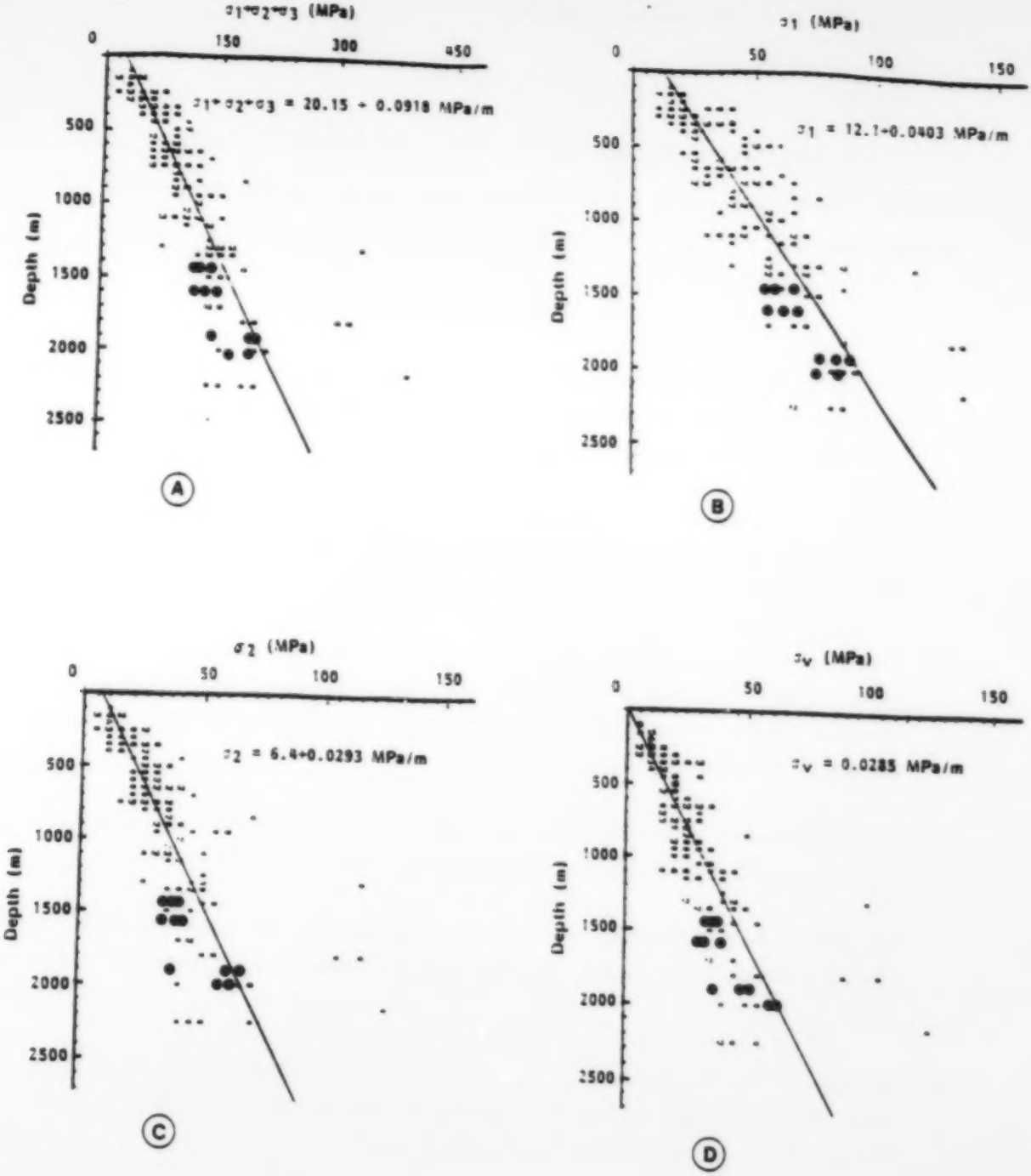

Fig. 5 - Increase of sum of principal stresses (A), maximum (B), and intermediate (C) principal stresses, and vertical stress components (D) as a function of depth in the Canadian Shield (7). (●) stress values at the Macassa Mine site.

mainly confined to the low range of the referenced data and no extreme values were determined at the Macassa Mine site.

ACKNOWLEDGEMENTS

The cooperation of Lac Minerals Ltd., especially G. Holmes, ground control technologist, for the assistance provided during the field work, is appreciated.

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